Journal of Theoretical Biology 359 (2014) 171–183

Contents lists available at ScienceDirect

Journal of Theoretical Biology

journal homepage: www.elsevier.com/locate/yjtbi

Older partner selection promotes the prevalence of cooperation in evolutionary games

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HIGHLIGHTS

- A co-evolutionary game entangled with strategy evolution and structure adaptation is proposed.
- The agent's aging process has much to do with the cooperation level and the network diversity.
- Age-based partner selection is proposed for strategy evolution.
- Older partner selection for strategy evolution fosters the prosperity of cooperation.

ARTICLE INFO

Article history:
Received 28 March 2014
Received in revised form
5 June 2014
Accepted 10 June 2014
Available online 20 June 2014

Keywords:
Evolutionary games
Spatial selection
Partner imitation
Agent's age
Cooperation and diversity

ABSTRACT

Evolutionary games typically come with the interplays between evolution of individual strategy and adaptation to network structure. How these dynamics in the co-evolution promote (or obstruct) the cooperation is regarded as an important topic in social, economic, and biological fields. Combining spatial selection with partner choice, the focus of this paper is to identify which neighbour should be selected as a role to imitate during the process of co-evolution. Age, an internal attribute and kind of local piece of information regarding the survivability of the agent, is a significant consideration for the selection strategy. The analysis and simulations presented, demonstrate that older partner selection for strategy imitation could foster the evolution of cooperation. The younger partner selection, however, may decrease the level of cooperation. Our model highlights the importance of agent's age on the promotion of cooperation in evolutionary games, both efficiently and effectively.

1. Introduction

The research on adaptive networks usually focusses on the interplay of *dynamics on networks* and *dynamics of networks* (Blasius and Gross, 2009; Gross and Blasius, 2008; Sayama et al., 2013), where many subjects are well studied. These dynamics range from neural systems (Bornholdt and Rohlf, 2000), epidemics spreading (Gross et al., 2006; Guerra and Gómez-Gardeñes, 2010), opinion formation (Holme and Newman, 2006; Zanette and Gil, 2006), evolutionary population (Broom and Cannings, 2013), voter model (Kozma and Barrat, 2008; Durrett et al., 2012; Vazquez et al., 2008; Vazquez and Eguíluz, 2008; Zschaler et al., 2012), swarm dynamics (Huepe et al., 2011; Del Genio and Gross, 2011), distributed task allocation (Abdallah and Lesser, 2007; Kota et al., 2012), social game dilemma (Zimmermann et al., 2000, 2004; Pacheco et al., 2006, 2006) etc. Among these studies in adaptive networks, social game dilemma attracts the most attention, and a large number of extensions (Perc and Szolnoki, 2010) based on game theory (Fudenberg and Tirole, 1991) are proposed to explore the evolutionary dynamics.

Past decades have witnessed the development of evolutionary dynamics (Lieberman et al., 2005) within adaptive networks, when evolutionary game theory (EGT) (Axelrod and Hamilton, 1981; Smith, 1993; Rand and Nowak, 2013; Nowak, 2013; Lieberman et al., 2005) was proposed and is being developed to address the subtleties of cooperation and defection that arise from co-evolution. Aiming at exploring the evolution of ecology, culture and behaviour within structured populations, EGT combines strategy evolution with topology adaptation tightly by two strategies, *cooperation* (C) and *defection* (D), interacting on a payoff matrix $(\begin{smallmatrix} R & S \\ T & P \end{smallmatrix})$. Depending on the relative order of the four values in the payoff matrix, three main dilemmas (Macy and Flache, 2002) are well known: Prisoner's Dilemma (PD) $T > R > P > S$, Stag-Hunt game (SH) $R > T > P > S$, and Snowdrift Game (SG) $T > R > S > P$. In order to make sense of the evolution of cooperation within structured networks, a large number of papers and simulations

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http://dx.doi.org/10.1016/j.jtbi.2014.06.013
0022-5193/

(Nowak et al., 2010; Santos et al., 2012) have been explored in these fields to shed light on the influence of co-evolutionary dynamics on the cooperation level.

Focussing on evolutionary dynamics, Nowak et al. (Nowak, 2012; Nowak et al., 2010; Tarnita et al., 2009; Rand and Nowak, 2013; Allen et al., 2013) have made great contributions to the theoretical work concerning evolutionary game theory, highlighting the idea that natural selection will be opposed to the evolution of cooperation unless it works together with some specific mechanisms, such as direct reciprocity, indirect reciprocity, spatial selection, multi-level selection, and kin selection. As mentioned above, not only the mutation and selection can affect the co-evolution process in cooperation dilemmas, but also the network topology plays a significant role. It thus seems very interesting to study the co-evolutionary dynamics, which means the interactions between evolving strategy and spatial selection. Combining *strategy evolution* with *structure adaptation*, the co-evolutionary dynamics make it possible that individuals can change their own strategies, meanwhile they are allowed to switch neighbours from one to another. In detail, this co-evolutionary process is controlled by a parameter: time scale ratio $W=\tau_e/\tau_a$, where τ_e is the time scale of the dynamics of strategies (i.e. strategy evolution) and τ_a is that of the dynamics of structures (i.e. structure adaptation) (Santos et al., 2006; Pacheco et al., 2006). When it comes to the dynamics of strategies, researchers usually concern about behaviour imitation or social learning (Pacheco et al., 2007; Van Segbroeck et al., 2012; Moreira et al., 2013), and adopt the pairwise comparison rule to update the strategies (Traulsen et al., 2009; Antal and Scheuring, 2006; Moreira et al., 2013). Besides, some other methods like richest-following rule (or 'learn from the best') (Abramson and Kuperman, 2001) and win-stay-lose-switch rule (Szabó and Fáth, 2007) are also applied to the dynamics of strategy. As for the dynamics of the structures, the majority of publications are mainly about rewiring from defective neighbours. That is to say if an agent is unsatisfied with an interaction (i.e. *adverse tie*), then that agent will redirect the adverse tie to someone else.

Based on the co-evolutionary framework refereed above, a variety of models have been developed to explain what will promote the evolution of cooperation. Focussing on the dynamics of network structures, Poncela et al. (2009) discussed the evolutionary games in a growing structured population, and explained the promotion of cooperation by network growing. Additionally, Szolnoki et al. showed that successful agents making new connections to pass their strategies would sustain cooperation (Szolnoki et al., 2009, 2008; Szolnoki and Perc, 2008; Szolnoki and Szabó, 2007), revealing the principle of '*successful become more successful*'. Wu et al. (2010) modelled the evolution of cooperation using Markov chains, and explained the reason why the fragile *CD* links and the robust *CC* links could bring cooperation prevalence. Reputation-based partner choice was proposed by Fu et al. (2008) to let the agents have a memory of the past interaction information, and then switch from lower-reputation neighbour to higher-reputation agents, promoting the cooperation effectively. Furthermore, Pacheco et al. (2006) presented an active liking model to describe the interplays between strategy and topology, showing that it was heterogeneity that stimulates cooperation to thrive. Santos et al. (2006, 2012, 2008, 2011) constructed a computational model with a fixed number of self-interested agents and social ties to investigate the emergence of long-term cooperation, where they explained that higher time scale ratio and pre-play signalling would bring higher level of cooperation as well as the structure diversity. Moreover, Van Segbroeck et al. (2010) produced research on the dynamics of competition and cooperation in the realms of social dilemma during the past decade, and encapsulated individual learning into the cooperation dilemma. Most notably, they illustrated that it was the diversity (in terms of network structure, response approach, selection pressure etc.) in adaptive social networks that improved the prevalence of cooperation (Van Segbroeck et al., 2008, 2009, 2011).

From what is presented above, it is known that the structure adaptation leading to heterogeneity can promote the evolution of cooperation. However, both imitation and rewiring are usually targeting those neighbours picked at random, where the partner selection strategies are overlooked. In order to make better sense of the spatial selection, this paper is focussed on examining the combination of partner selection and the co-evolutionary dynamics. By introducing the notion of *aging agents*, which is another dimension for the evolutionary games, we shed light on the influence of agent's age on the cooperation level and network structure. Given the basic model for coupled dynamics of strategy and structure, three different age-based partner selections for strategy imitation: *older selection*, *random selection* and *younger selection* are presented. Then a series of simulations are undertaken to analyse the fraction of cooperators, degree diversity and age diversity. Finally, the paper discusses the implications to the model made by changing relative time scale as well as the rewiring strength. The conclusion from the analyses shows that older partner selection for strategy imitation will lead to a high level of cooperation.

2. Co-evolutionary model

Here, we study this issue in the framework of prisoner's dilemma (PD) games, and there are two types of agents in a connected world: one is *cooperator* (C) and another *defector* (D). Individuals interact each other within a network, and if there is a link between two nodes, then they meet and interact based on the payoff matrix:

$$M=\begin{array}{c} \\ C \\ D \end{array}\begin{array}{c} \begin{array}{cc} C & D \end{array} \\ \begin{pmatrix} R & S \\ T & P \end{pmatrix} \end{array} \quad (1)$$

We define a reward R for mutual cooperation, while a punishment P for mutual defection. And, if one cooperates but another defects, then C agent will receive a sucker's payoff S while D agent will get the temptation T to defect. A prisoner's dilemma PD ($T>R>P>S$) usually requires the players to opt for defection which always demonstrates a better profit because $T>R$ and $P>S$. And any agent in PD will be satisfied with the agents with strategy C and unsatisfied with those with D. The fitness of an agent is to accumulate all the interactions with its immediate neighbours:

$$\Pi_i=\sum_{j\in Nei_i} M(s_i,s_j) \quad (2)$$

where Nei_i is the immediate neighbourhood of agent i and s_i represents the corresponding strategy.

Besides, we assume that the number of agents (N) and links (E) remains constant during the co-evolution, which implies the limitation of resource and topology in social dilemma. And each agent only has the local information (e.g. strategy, fitness of its immediate neighbours) to react during the coupling process as follows.

2.1. Strategy evolution

The strategy of an agent reacting in a complex environment should change over time to achieve a higher fitness or avoid hurts from its neighbours. Usually, agents can observe and imitate the experiences and behaviour of the successful ones, which is a main